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On the Latitude Distribution of the Polar Magnetic Flux as Observed by SOLIS-VSM

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Abstract.

Magnetograms from the Vector SpectroMagnetograph (VSM) of the Synoptic Optical Long-term Investigations of the Sun (SOLIS) project are utilized to study the latitude distribution of magnetic flux elements as a function of latitude in the polar solar caps. We find that the density distribution of the magnetic flux normalized by the surface of the polar cap and averaged over months decreases close to the solar poles. This trend is more pronounced when considering only flux elements with relatively large size. The flux density of the latter is relatively flat from the edge of the polar cap up to latitudes of 70° – 75° and decreases significantly to the solar pole. The density of smaller flux features is more uniformly distributed although the decrease is still present but less pronounced. This result is important in studying meridional flows that bring the magnetic flux from lower to higher solar latitudes resulting in the solar cycle reversal. The results are also of importance in studying polar structures contributing to the fast solar wind, such as polar plumes.

1. Introduction

Polar regions of the Sun harbor numerous challenging solar phenomena, such as the source and acceleration process of the fast solar wind. Although it is widely believed that the magnetic field is main driver of most physical processes within the solar polar areas, these areas are not adequately characterized for observational and instrumental limitation reasons.

Several solar phenomena (i.e., solar differential rotation, supergranular diffusion and meridional flows) couple together to transport poleward the mid-latitude magnetic flux of decaying active regions. This process leads to the formation of polar caps and their evolution through the solar cycle (see Babcock & Babcock 1955; Leighton 1964; DeVore & Sheeley 1987; Sheeley, Nash, & Wang 1987; etc.). Solar meridional flows have been shown, both observationally and theoretically, to be the main mechanism of zonal flux transport (Howard 1974; Durrant, Turner, & Wilson 2004; Duvall 1979; LaBonte & Howard 1982). However, the weak flow, of few times 10 m s^{-1} at best, is not easily measurable and direct measurements can not be achieved beyond solar mid-latitudes ($\sim 45^\circ$). Thus, it is important to obtain additional constraints on these flows close to the solar poles, which would be of great use for solar dynamo and flux transport models.

Raouafi, Harvey & Solanki (2006a,b; 2007) studied polar plumes EUV spectral emissions using different models. By comparing theoretical results to observations, they found that polar plumes would preferentially be based more than 10° away from the solar pole. Saito (1958) noticed that white-light plumes in

eclipse observations were also rooted close to polar hole edges. The study of the polar flux latitude-distribution would confirm Raouafi et al.'s findings and constrain the magnetic flux transport (e.g., meridional flows) that drive such a distribution.

2. Observations and Data Analysis

Line-of-sight (LOS) chromospheric (e.g., Ca II 854.2 nm) magnetograms from the VSM SpectroMagnetograph (VSM; Jones et al. 2002) are utilized to characterize the latitude distribution of magnetic flux elements in the northern polar cap during June-November 2007. The VSM is part of the Synoptic Optical Long-term Investigations of the Sun (SOLIS; Keller, Harvey & Giampapa 2003). The LOS-chromospheric component of the magnetic field benefits from the canopy structure at this height providing a strong signal near the limb (see left panel of Figure 1). To further improve the signal, in particular close to the limb, a normalizing radial correction described by Raouafi, Harvey & Henney (2007) is applied to every magnetogram (see right panel of Figure 1). A threshold on the field strength is subtracted from the magnetograms to suppress the noise.

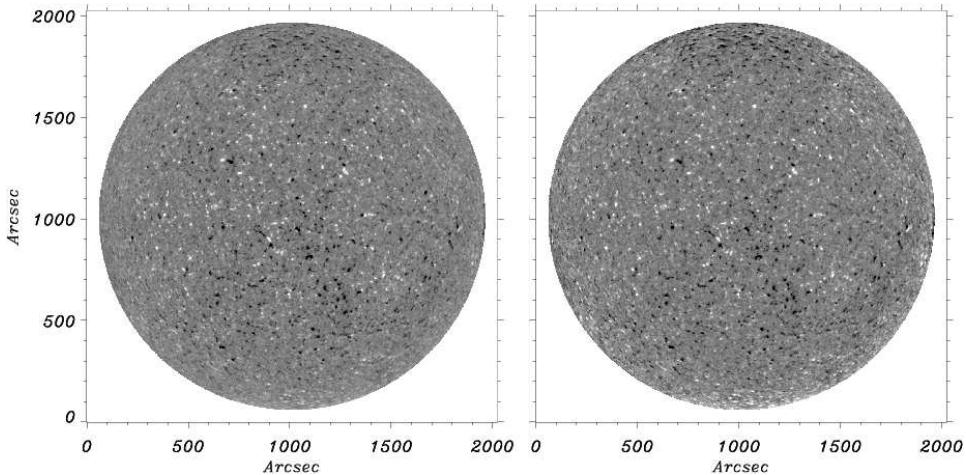


Figure 1. SOLIS/VSM-chromospheric (Ca II 854.2 nm; Sep. 11, 2007) LOS-magnetogram with (right) and without (left) radial correction.

Magnetic flux elements are selected by applying a top-hat operator that selects the intensity peaks in the magnetic field strength of each polarity map. This operator uses a disk structuring element with sizable radius to select the prominent peaks with base sizes larger than the structuring disk element. A shape constraint can also be included in the structuring element. Weak-diffuse magnetic fields are ignored in the selection process. Once magnetic elements of interest are identified, their locations in terms of latitude and longitude are determined by averaging the coordinates of the contour of each of them. The distribution of the selected elements as a function of latitude is obtained by determining the average location for every selected feature. However, the obtained distribution is absolute and might be biased by the latitude area dependence.

In order to avoid that, the obtained distribution are normalized by the latitude area distribution taking into account the solar geometry (i.e., B_0 angle). Since single histograms do not show clearly the distribution of magnetic flux elements due to statistical reasons, they are monthly averaged.

3. Results

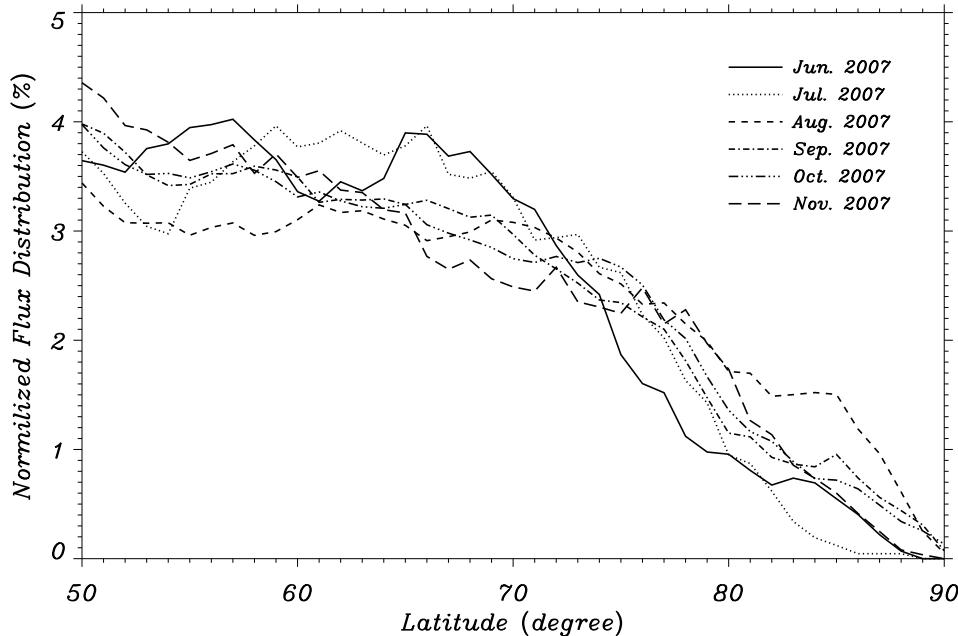


Figure 2. Monthly normalized magnetic flux distribution as a function of latitude for the north polar cap from June through November 2007. Distributions from individual magnetograms have been normalized by the observable area surface curve. The tilt angle of the solar axis, B_0 , is taken into account. Smoothing by 3 bins of latitude has applied to the different curves to reduce the statistical noise in the distribution.

The normalized flux element density is plotted in Figure 2 for each monthly period from June through November 2007. The histogram obtained from every magnetogram is divided by the area surface curve computed taking into account the corresponding tilt angle, B_0 , of the polar axis of the Sun. This is to remove any bias in the distribution that might be due to the decrease of the observable surface area with latitude. The correspondence between the different curves and time is displayed on the same Figure. The curves are smoothed by 3 bins of latitude in order to reduce statistical variations. It is noticeable how the overall variation trend is similar for all the different curves

The distribution density of polar flux elements normalized by the surface area is relatively constant from mid-latitudes up to about 65° - 70° with a slight increase in the equatorial direction. Beyond latitude 70° the decrease in the density distribution is significant with a nearly constant slope to the pole. These results are in complete agreement with previous ones of the period of time spreading

from September to December of 2006 (see Raouafi, Harvey, & Henney 2007) showing that flux concentration elements are more abundant near the edge of the polar cap than near the solar pole. Bearing in mind that flux concentrations form the base of coronal polar plumes, our results are also compatible with ones found by Raouafi, Harvey & Solanki (2007) showing that polar plumes would preferentially be rooted away from the solar pole by more than 10° .

4. Conclusion and Discussion

The high quality of magnetograms from SOLIS allowed us to characterize the flux concentration distribution as a function of latitude over a relatively large period of time. This was not possible earlier mainly because of instrumental limitations. The obtained results are important for studies of magnetic flux transport. They provide additional constraints on solar phenomena such as meridional circulation that is not possible to measure beyond $45^\circ - 50^\circ$ nor how it functions near solar poles. Meridional flows, for instance, are an important input for solar dynamo and flux transport models. Our results on the density distribution of the magnetic flux concentrations at the polar regions suggests that the mechanisms responsible for the flux transport increasingly lose strength within the last 20 degree latitude before reaching the solar poles.

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